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Data Throughput of CDMA-HDR a High Efficiency-High Data Rate Personal Communication Wireless System

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Abstract – Forward link data throughput performance of a high data rate wireless access system is presented. On the forward link of the proposed system data is transmitted to different access terminals (AT) in a TDM fashion. The rate transmitted to each AT is variable and depends on each AT's measured SINR. ATs send to the access points (AP) the index of the highest data rate which can be received reliably. A scheduler at the AP determines the next terminal to be served based on the reported data rate requests from the terminals and the amount of data that has already been transmitted to each terminal. A cell layout of 19 3-sector and 6-sector hexagonal cells is considered. Throughput of the forward link of the embedded sector is simulated for stationary terminals.

I. Introduction

The objective of this paper is to estimate forward link throughput of a high data rate system proposed in [1] for wireless access to data networks. The forward link of the proposed system consists of a single data channel that is divided into 1.67 msec time slots. Two pilot bursts are inserted into each time slot to aid in synchronization, signal to interference plus noise ratio (SINR) estimation and coherent demodulation. Control channels and user payload are time multiplexed onto the forward link. The spreading bandwidth is 1.2288 MHz as for IS-95 systems. The data rates supported on the forward link are 38.4, 76.8, 102.4, 153.6, 204.8, 307.2, 614.4 and 921.6 kbps, and 1.2, 1.8 and 2.4 Mbps. One of three modulation schemes QPSK, 8PSK and 16QAM is used depending on the data rate. Turbo codes are used for error correction. Depending on the data rate, a forward link packet may occupy from 1 up to 16 time slots. The access terminals (AT) predict the SINR and compute the rate that the predicted SINR can support while maintaining a given frame error rate. Additionally, the AT updates and transmits a 4-bit data rate control (DRC) sequence to the Access Point (AP) requesting the computed rate every 1.67 ms. The AP transmits packet datas at the rate requested by the AT. When there are multiple users requesting data, a scheduler determines the order in which the access terminals are served.

This paper provides simulation results for the average data throughput in one sector of the center cell of a cluster of cells consisting of 3 tiers of cells. In this paper we have focused on determining the average throughput of a sector. The averaging is done with the assumption that the users are uniformly distributed in the sector. The average throughput of a sector differs from the peak rate supported on the forward link because the actual transmission rate to the

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access terminal depends upon the channel condition at the time of transmission.

For frequency reuse of 1, the system achieves spectral efficiencies in the order of 1.7 bps/Hz/site with single receive antenna and close to 3 bps/Hz/site with dual receiver diversity in a 3-sector network configuration.

Section 2.1 describes the details of the path loss models and link level fading models used in estimating the data rate that an AT may support. Section 3 provides a description of schedulers used in computing the throughput. Throughput results are given in Section 4 and conclusions are given in Section 5.

2. Simulation Model

In the simulations, ATs are placed in the sector according to uniform distribution. The SINR seen by the AT from each of the sectors in the cell layout is computed. The best sector (server) for the AT is chosen as the sector from which the AT receives the largest SINR. Once the SINR of the best server is computed, then the data rate (DRC) that the SINR supports is determined. Note that a DRC (data rate) is determined every 1.67 msec. By replacing the mobile in different locations in the center sector, a sequence of DRCs that the mobile can support is generated as a function of time. A scheduler then uses these DRCs to determine the order and the data rate in which to transmit data to users on the forward link. The scheduler computes the average forward link throughput. The description of the scheduler is given below.

Path loss, large scale shadowing, and small scale temporal fading are included in the SINR computation. Large scale fading is modeled by log-normal shadowing with standard deviation of 8 dB. Small scale temporal fading is modeled as Rayleigh for mobile applications and as Ricean for stationary applications. In simulating stationary terminals in buildings an additional spatial static fading is included in the model. The spatial fading models the standing wave pattern inside buildings.

Measurements of the channel impulse response at carrier frequency of 1.9 GHz and bandwidth of 1.23 MHz were made in a number of office buildings. The spatial fading is modeled by Rayleigh distribution. The data was also analyzed to model temporal fading variations. Even if the terminal is stationary the "world" around it produces temporal fading variations that need to be modeled. Ricean distribution with different values (K) of specular to diffused components ratios were compared to the distribution of temporal fading of the measured data. It was observed that best fit K values between the measured data and theoretical distributions ranged mainly from 0 to 12 dB with median of about 6 dB. The Doppler frequency of the temporal variations ranges primarily in the 1 to 2 Hz. Therefore, in the simulation of stationary indoor terminals Rayleigh static spatial fading and Ricean temporal fading with various K values ranging uniformly between 0 and 12 dB and Doppler ranging uniformly between 1 to 2 Hz are assumed. Multipath is modeled by two paths. The power fractions on the two paths were assumed to be 0.75 and 0.25, i.e. a primary path and a secondary multipath component 5 dB down from the primary.

Once a random location according to uniform distribution across the sector coverage is determined for the AT as described above, the AT's location is unchanged for 30 seconds (equivalent of 18000 times slots) in order to include the temporal fading variations' impact on the DRC (data rates) estimates. After 18000 time slots, a new location is determined according to the uniform distribution. A total of 50 locations are generated for each AT. In order to simulate multiple simultaneous users, independent sequences of DRCs are generated for each AT as

described above. In summary, for a single AT, at each location the simulation will run for 18,000 slots equivalent to 30 seconds of real time. For a total of 50 locations the simulation will run for 50 * 30 seconds or 25 minutes equivalent of real time. With multiple simultaneous AT's, each one will undergo the same scenario, i.e. 25 min equivalent real time for each AT.

Single antenna and dual receive antennas are simulated at the AT. The dual antenna systems use dual receivers and the MMSE (Minimum Mean Square Error) combiner [2]. The dual MMSE combiner provides interference suppression capability that is mainly effective when there is a single dominant interferer. The MMSE combiner is also effective in reducing multipath interference for terminals near the cell site where there is little out of cell interference.

3. Forward Link Schedulers

The scheduler attempts to take advantage of the temporal variations of the channel by scheduling transmissions to ATs during time periods where the ATs see strong signal levels. The scheduler sends data to the mobile that has the highest *DRC/R*. *DRC* is the rate requested by the mobile in a given slot and *R* is the average rate received by the mobile over a window of appropriate size. This way, each user is served in slots in which its requested rate is closer to the peak compared to its recent requests.

To be specific, let us suppose that there are N users and let $R_i(t)$ be the estimate of the average rate for user i at slot t, $i= 1,..,N$. Also, let us suppose that at slot t, the current DRC (i.e., requested rate) from user i is $DRC_i(t)$, again $i=1,..,N$. The algorithm works as follows:

1. Scheduling: The user with the highest ratio of $DRC_i(t)/R_i(t)$ out of all N users will receive transmission at each decision time. Ties are broken randomly. Any user for whom there is no data to send is ignored in this calculation.
2. Update Average Rate: For each user i
   $R_i\ (t+1)\ =\ (1-1/t_c)\ R_i\ (t)\ +\ 1/t_c\ *\ Current\_Transmission\_Rate\_of\_User\_i.$
   A user that is not currently receiving service has 0 for his current rate of transmission. Even users for whom the scheduler has no data to send also get their average rate updated. Note that the scheduling step is executed each time a new transmission begins but the update average rate is done in each slot, even if the slot is in the middle of a multi-slot transmission.

The update of the average rate as specified here is done using a low pass filter with a time constant of t_c slots. In our simulation, we assumed t_c=1000 slots (1.66... seconds).

3.1 Discussion of the Scheduling Algorithm

The scheduler used for HDR provides fairness in the following sense. If we use another scheduling algorithm to increase the throughput of a specific user by x% over what that user receives under the HDR scheduling algorithm, the summation of all the percentage decreases suffered by the throughputs of all the other users under the new algorithm will be more than x%. This is known as the proportional fairness criteria [4]. In this sense, HDR scheduling algorithm is the best possible algorithm.

The value of the parameter t_c used by the scheduling algorithm is related to the maximum amount of time for which an individual user can be starved (i.e., not receive service). Note that this will happen when a user abruptly moves from a good channel environment to a bad channel environment. This is because the algorithm attempts to serve each user at the peak of its channel condition. Hence, the scheduler will see a drop in channel condition as temporary until the poor channel conditions persists for more than t_c seconds. A higher value of t_c

allows the scheduler to wait longer for a user's channel condition to improve and hence improves overall throughput. On the other hand, a large t_c also means that packets for a specific user may be delayed by t_c if the user's channel conditions deteriorates abruptly. We have picked a value of t_c that appears in our simulation to be good compromise between these two competing requirements.

4. Simulation Results

Figure 1 shows average forward link throughput per sector for frequency reuse of 1 for single receiver/antenna at the access terminal for omni, 3 sector and 6 sector configurations; Figure 2 shows throughput results for two receivers/antennas at the AT. Antenna beamwidth of 65 and 33 degrees are assumed for the 3 sector and 6 sector deployments. The simulations assume that all sectors of all base stations in the 19 cell cluster are transmitting 100% of the time, i.e. generating maximum load. The throughput results for the sector under consideration corresponds to the maximum throughput when the base station continuously transmits data. As can be seen from Figures 1 and 2, the sectorization gain of the 3-sector cells is about 2.4 compared to an Omni cell; the sectorization gain of 6-sector cells is about 4.4 compared to an Omni cell.

Note that the throughput in Figures 1 to 2 for one simultaneous user corresponds to the equal time scheduling algorithm. The equal time scheduler gives an equal amount of time to each user in a round robin fashion.

As can be seen from the figures, the throughput of a cell increases significantly when ATs have 2 antennas/receivers as compared to having one antenna. This is true for both scheduling algorithms, the proportionally fair and the equal time schedulers. However, there is significant difference between the performance of two scheduling algorithms. In both Figures 1 and 2, the cell throughput increases consistently under proportionally fair scheduler when the number of ATs in the cell is increased. The increase in the sector throughput with increasing number of users is attributed to user diversity. That is, the scheduler waits for each AT's requested rate to become higher than its own average and then sends data to that AT. Having more users increases the likelihood that the mobiles are served near the peaks of their requested rates. However, the percentage gains in cell throughput when number of users is increased are smaller for 2-antenna case (from 920kb/s to 1.18Mb/s, or 28% for frequency reuse of 1 and 3 sector configuration) than for 1-antenna case (from 460kb/s to 690 kb/s, or 50%).

5. Conclusions

In this paper we have presented the throughput performance of CDMA-HDR. The system described achieves excellent performance due to the flexible and efficient rate control scheme, and the scheduling algorithm which takes advantage of the inherent multi-users diversity of a mobile wireless system, and advanced signal processing techniques. The system dedicates a 1.25 MHz RF carrier to data services. The combination of IS-95 and its evolutions (G3G MC1X) for voice services and CDMA-HDR for packet data services provide the most efficient solution to both services.

References

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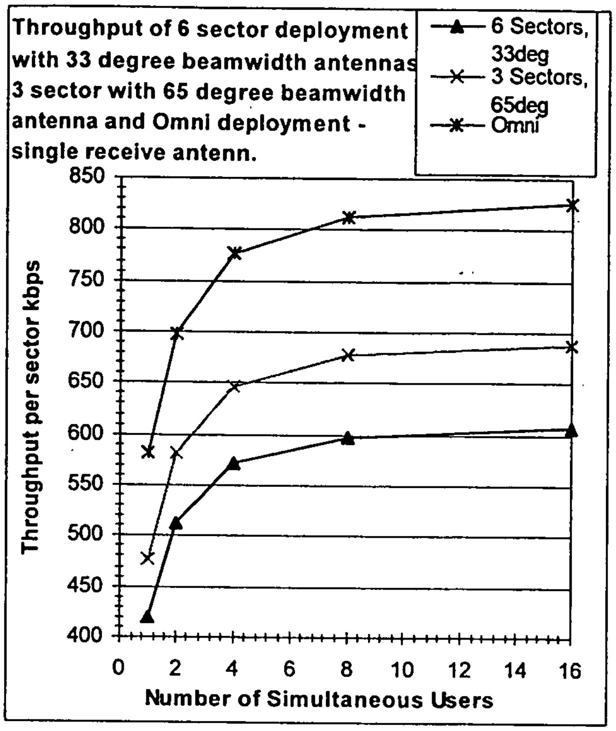

Figure 1. Average throughput per sector for frequency reuse of 1 and 1 receive antenna.

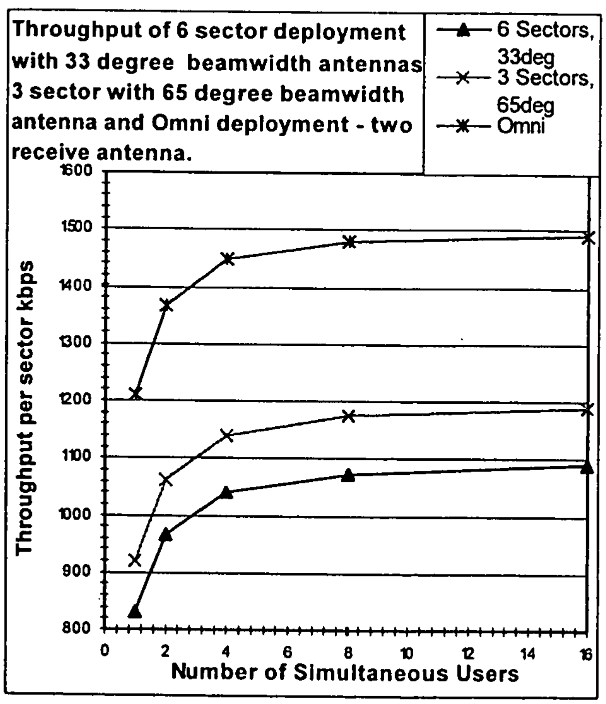

Figure 2. Average throughput per sector for frequency reuse of 1 and 2 receive antennas.